U. S. NAVAL SUBMARINE MEDICAL CENTER

Submarine Base, Groton, Conn.

REPORT NO. 464

RECOVERY OF FOVEAL ACUITY FOLLOWING EXPOSURE TO VARIOUS INTENSITIES AND DURATIONS OF LIGHT

by

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Research Work-Unit MF022.03.03-9011.02

Released by:

J. L. Waite, CAPT MC USN
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U. S. Naval Submarine Medical Center

16 December 1965

SUMMARY PAGE

THE PROBLEM

To determine the effect of various durations and intensities of light-flashes on the ability of an individual to see detail with dark-adapted vision.

FINDINGS

The times necessary to re-adapt to optimal acuity vary systematically with the intensity and duration of the exposure. These times range from essentially zero for dim, brief lights, to a maximum of about five minutes for longer, brighter ones. The product of $I \times T$ gives a constant effect so that when readaptation time is plotted against $I \times T$, a single curve results which adequately fits the data points.

APPLICATIONS

Many tasks, such as those of a periscope operator, a pilot, or a lookout, require the ability to discriminate a target in a dark surround and not merely to determine the presence or absence of a light. A person who has reached the state of maximum night time acuity through dark adaptation may be exposed to brief flashes of light. This study provides quantitative answers, based on the intensity and duration of the light, to the question of how much time in the dark is necessary for that person to recover optimal acuity.

ADMINISTRATIVE INFORMATION

This investigation was conducted as a part of Bureau of Medicine and Surgery Research Work-Unit MF022.03.03-9011—Studies of Target Detection and Discrimination in Submarine Operation. The present report is the second to be published on this Work-Unit. It was approved for publication on 25 March 1965, sent to The American Journal of Psychology, and subsequently published in that journal, Vol. LXXVIII, Sept 1965, pp. 432-440. It has been designated as SMRL Report Number 464.

Founded in 1887 by STANLEY HALL

OFFPRINTED FROM

THE AMERICAN JOURNAL OF PSYCHOLOGY

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September, 1965, Vol. LXXVIII
pp. 432-440

Published by The American Journal of Psychology, Department of Psychology, University of Texas, Austin, Tex.

RECOVERY OF FOVEAL ACUITY FOLLOWING EXPOSURE TO VARIOUS INTENSITIES AND DURATIONS OF LIGHT*

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In any situation in which the eye is used at dim levels of illumination, the effect of a brief exposure of bright light on the dark-adapted fovea has many practical consequences. The usual tasks performed in such a situation involve foveal acuity, as the individual turns his attention and his fixation toward the target that must be resolved. Despite its importance, few data are concerned with this problem of the recovery of foveal acuity.

Related experimentation has been concentrated in the following areas: (a) the investigation of the course of foveal dark-adaptation[1] and the effect of brief light-exposures on this light sensitivity;[2] (b) atomic-blast studies involving the effect of very brief (μ and m.sec.) and uniquely intense flashes on acuity;[3] (c) foveal acuity-studies after complete light-

* Received for publication April 3, 1964. From the U.S. Naval Medical Research Laboratory, Groton, Connecticut.

[1] Selig Hecht, The nature of foveal dark adaptation, *J. gen. Physiol.*, 4, 1921, 113-139; Selig Hecht, Charles Haig, and A. M. Chase, The influence of light adaptation on subsequent dark adaptation of the eye, *J. gen. Physiol.*, 20, 1937, 831-850.

[2] B. H. Crawford, Photochemical laws and visual phenomena, *Proc. Roy. Soc.*, Series B, 133, 1946, 63-75; F. A. Mote and A. J. Riopelle, The effect of varying the intensity and the duration of pre-exposure upon foveal dark adaptation in the human eye, *J. gen. Physiol.*, 34, 1951, 657-674; D. E. Johannsen, P. I. McBride, and J. W. Wulfeck, Studies on dark adaptation: I. The pre-exposure tolerance of the dark-adapted fovea, *J. opt. Soc. Amer.*, 46, 1956, 67-71; II. The pre-exposure tolerance of the human fovea adapted to different brightness levels, *ibid.*, 266-269.

[3] G. T. Chisum and J. H. Hill, Flash blindness recovery time following exposure to high-intensity short-duration flashes, U.S. Naval Air Development Center, Johnsville, Pa., 27 November 1961, NADC-MA-6142; S. L. Severin, Recovery of visual discrimination after high intensity flashes of light, School of Aerospace Medicine, USAF Aerospace Medical Center, Brooks AFB, Texas, December 1961, Report No. 62-16; S. L. Severin, N. L. Newton, and J. F. Culver, A study of photostress and flash blindness, USAF School of Aerospace Medicine, Brooks AFB, Tex., December 1962, SAM-TDR-62-144; J. F. Parker, Jr., Visual impairment from exposure to high intensity light sources, Office of Naval Research. Report prepared by Bio-Technology, Inc. under contract Nonr-4022(00). May 1963; S. L. Severin, A. V. Alder, N. L. Newton, and J. F. Culver, Photostress and flash blindness in aerospace operations, USAF School of Aerospace Medicine, Brooks AFB, Texas, September 1963, SAM-TDR-63-67.

adaptation of 5 to 10 min.;[4] and (d) the effect of brief light-exposures on peripheral light-sensitivity[5] and acuity.[6]

These studies indicate that foveal sensitivity to dim lights improves very rapidly with dark-adaptation, and that recovery of foveal dark-adaptation depends upon the intensity and the duration of the adapting source. They show, further, that the luminance required for resolution of a target, after complete light-adaptation, decreases with time in the dark. The curves are similar to those of simple foveal dark-adaptation, except that the final acuity-threshold is higher than the light-threshold and depends on the size of the target to be resolved. From these researches, we are also able to estimate the amount of time necessary to recover peripheral sensitivity after exposure to brief, bright lights.

Although these findings are important in themselves, they do not answer the question of how soon a dark-adapted fovea recovers its ability to discriminate targets in a darkened surround after exposure to a light flash of usual intensity and duration. It will be the purpose of this study to determine this function.

Apparatus. All measurements were made with a Hecht-Shlaer adaptometer.[7] The preadaptation-luminances were produced by the mechanism provided for this purpose in the instrument. A common source, in this case a 40-w. tungsten bulb, provided the light for both the preadaptation- and the test-stimuli. For the pre-

[4] J. L. Brown, C. H Graham, Herschel Leibowitz, and H. B. Ranken, Luminance thresholds for the resolution of visual detail during dark adaptation, *J. opt. Soc. Amer.*, 43, 1953, 197-202; Brown, Effect of different preadapting luminances on the resolution of visual detail during dark adaptation, *ibid.*, 44, 1954, 48-55.

[5] L. K. Allen and K. M. Dallenbach, The effect of light-flashes during the course of dark-adaptation, this JOURNAL, 51, 1938, 540-548; E. A. Suchman and H. P. Weld, The effect of light-flashes during the course of dark adaptation, this JOURNAL, 51, 1938, 717-726; Charles Haig, The course of rod dark adaptation as influenced by the intensity and duration of pre-adaptation to light, *J. gen. Physiol.*, 24, 1941, 735-751; George Wald and A. B. Clark, Visual adaptation and chemistry of the rods, *J. gen. Psychol.*, 21, 1937, 93-105; Mote and Riopelle, The effect of varying the intensity and the duration of pre-exposure upon subsequent dark adaptation in the human eye, *J. comp. physiol. Psychol.*, 46, 1953, 49-55; The effect of varying the light-dark ratio of intermittent pre-exposure upon subsequent dark adaptation in the human eye, *J. opt. Soc. Amer.*, 41, 1951, 120-124; S. M. Luria and J. A. S. Kinney, The interruption of dark adaptation, U.S. Naval Medical Research Laboratory, Groton, Conn., Vol. 20 (Report No. 347), 1 Feb. 1961.

[6] A. L. Diamond and A. S. Gilinsky, Luminance thresholds for the resolution of visual detail during dark adaptation following different durations of light adaptation, USAF Air Research Development Command, Wright-Patterson AFB, Aero Med. Lab. April 1952, WADC-Tech. Rep. 52-257; G. A. Fry and Mathew Alpern, Effect of flashes of light on night visual acuity, Wright Air Development Center, WADC Tech. Rep. 52-10, Part I, November 1951.

[7] Selig Hecht and Simon Schlaer, Adaptometer for measuring human dark adaptation, *J. opt. Soc. Amer.*, 28, 1938, 269-275.

adaptation-stimuli, the light from the source, projected by a series of lenses to a Maxwellian view, subtended approximately 35° at the *O*'s position. Six settings of preadaptation-stimuli were used, ranging from 0.36 ft.-L to 3,000 ft.-L.

The test-stimulus was a circular acuity-grid, 1° in diameter, whose luminance could be varied by neutral filters and a neutral density-wedge. The bars of the grid, alternately opaque and transparent, subtended 6 minutes of visual angle yielding a visual acuity of 0.2. Two fixation-points were provided, one on either side of the acuity-grid, and *O* was instructed to fixate the center area between them where the test-stimulus would appear.

Procedure. The *O* first dark-adapted for 5 min.; then measures were made of his acuity-threshold by a method of constant stimuli. The adaptation-source was then presented for a given interval and the course of readaptation to the previously determined threshold was measured. Since foveal adaptation often proceeds very quickly, a single curve could not be determined all at once; therefore the following procedure was adopted: The acuity-grid was set at a predetermined level of luminance above final threshold and was presented repeatedly for one second at 5 sec. intervals until the *O* reported seeing it. If the first level was considerably above final threshold, a second lower luminance-level was then set and the procedure repeated. To fill in other points in the curve, the adaptation-source was presented again and the test-stimulus set at different luminance-values. Sufficient time was allowed between presentations of the adaptation-source to assure that the *O* always started from the completely dark-adapted condition. All the durations for a given adapting luminance were measured in one session with the order of presentation of durations randomized within the session. At least three sessions were run for each adaptation-level. Three *O*s, corrected when necessary to 20/20 vision, were run on all conditions. All observations were made with the right eye.

Results. The average threshold, after complete foveal dark-adaptation, for the 0.2 visual acuity-target was approximately 7.0 log μμL or 0.01 ft.-L. After exposure to the various adaptation-sources, the luminances required to resolve the target were increased, and varying lengths of time in the dark were needed to return to this thrshold. Fig. 1–3 show the recovery-curves averaged for the three *O*s for the various durations of constant luminance. For example, in Fig. 1, after 45 sec. of 3,000 ft.-L., the initial threshold was raised more than 2 log units and it required about 4 min. in the dark for the final threshold of 7.0 log μμL. to be regained. At the other extreme, after 1.5 sec. of 3,000 ft.-L., only 26 sec. were required for recovery.[8] The obvious differences between these families of curves for the various luminances of exposure are that the initial thresh-

[8] As long as the adapting stimulus fills the fovea, its size should not be a factor in foveal readaptation-time (J. A. Hanson, E. M. S. Anderson, and R. P. Winterberg, Studies on dark adaptation: V. Effect of various sizes of centrally fixated pre-exposure fields on foveal and peripheral dark adaptation, *J. opt. Soc. Amer.*, 50, 1960, 895-899). Nevertheless, as a check on this, the adapting field was cut to 4° for one unreported series of curves; the resulting data were the same as for the 35° field-size.

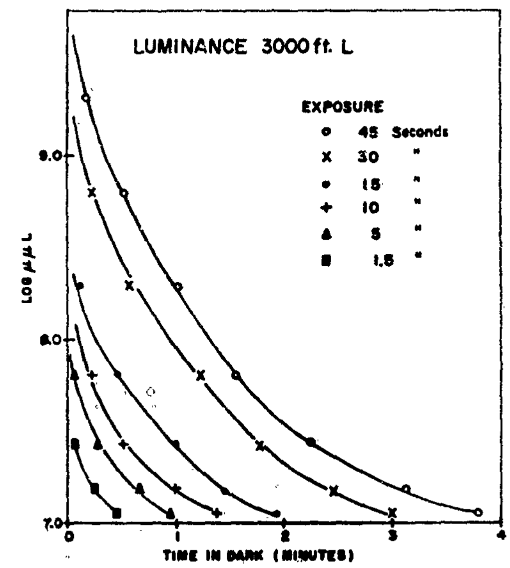

FIG. 1. READAPTATION FOLLOWING EXPOSURE TO 3,000 FT.-L. FOR VARIOUS DURATIONS

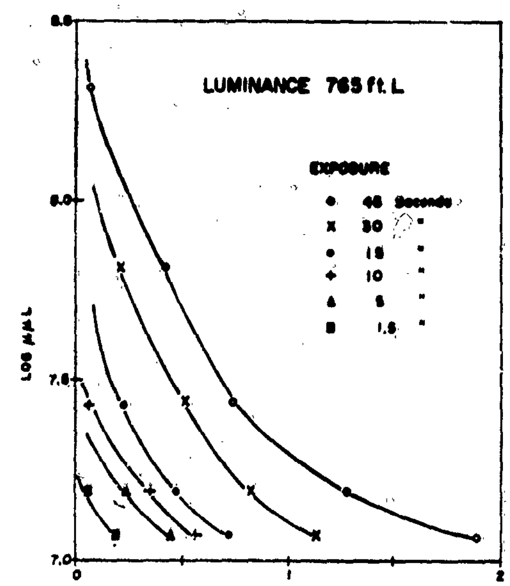

FIG. 2. READAPTATION FOLLOWING EXPOSURE TO 765 FT.-L. FOR VARIOUS DURATIONS

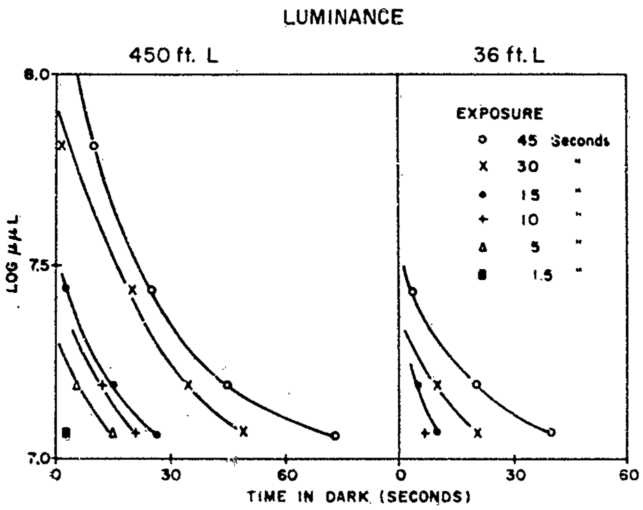

FIG. 3. READAPTATION FOLLOWING EXPOSURE TO 450 FT.-L. AND TO 36 FT.-L. FOR VARIOUS DURATIONS

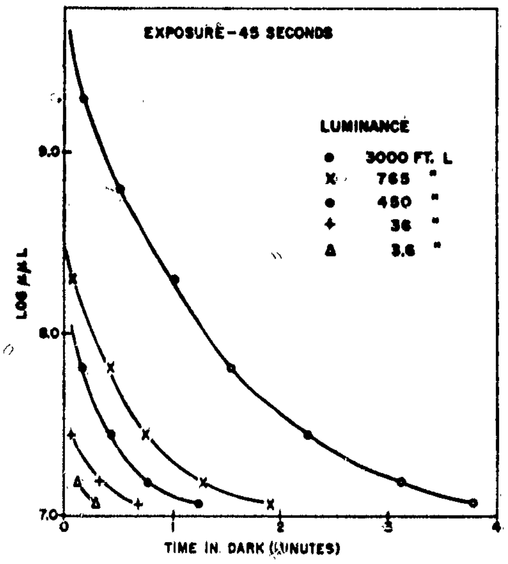

FIG. 4. READAPTATION FOLLOWING EXPOSURE FOR 45 SEC. OF VARIOUS LUMINANCES

old is higher and the total time to readapt longer for the brighter sources.

This point can be made more explicit by plotting the same data with intensity the parameter rather than time. Fig. 4 is an example of this treatment for a duration of 45 sec. With this length of time it was possible to measure an effect of 3.6 ft.-L., but with 0.36 ft.-L., no effect on foveal acuity was found for any length of time.

The data presented thus far have been the averages of 3 *Os* and there are, of course, individual differences. Regular families of curves were

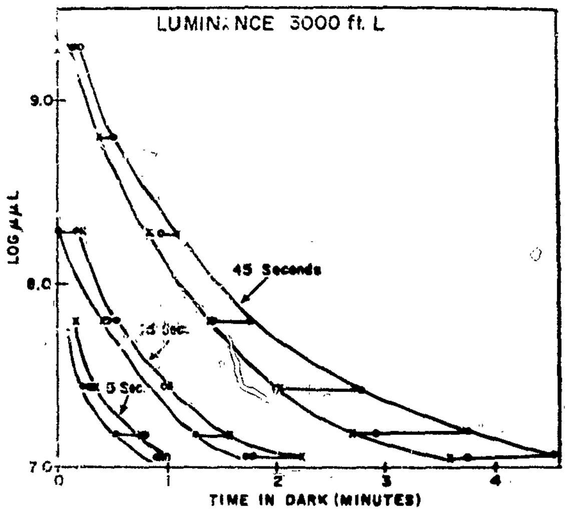

FIG. 5. INDIVIDUAL DIFFERENCES IN READAPTATION FOLLOWING EXPOSURE TO 3,000 FT.-L. FOR 5, 15, AND 45 SEC.

found, however for each *O*; the initial threshold and the total time to readapt varied systematically with the intensity and duration of the adaptation-source in the same way as was shown in the average curves. Fig. 5 is an example of the individual variations. Here the exposure-times of 45, 15 and 5 sec. are given at 3,000 ft.-L., the luminance at which the largest individual differences were found. The horizontal lines indicate the range of these differences. Thus, after 45 sec. the extreme values for the final threshold were 3.5 to 4.5 min. and after 5-sec. exposure, 50 to 60 sec. Individual differences are thus minor compared to the effects of the glare source.

Since the data suggested a reciprocal relationship between intensity and time of the adaptation-source, the results for the various time-intensity

combinations were tabulated and are shown in Fig. 6. The total time necessary for the fovea to readapt to threshold is plotted as a function of the log of the product of intensity and duration of the source. A single line was found to represent most of the data-points. The curve starts at a level of very little effect, 10 sec. or less of readaptation-time, and rises sharply to an asymptote of 4–5 min. with large values of intensity × time.

Discussion. Fig. 6 has shown reciprocity between intensity and time of exposure to light, as measured by the total time to readapt, for a re-

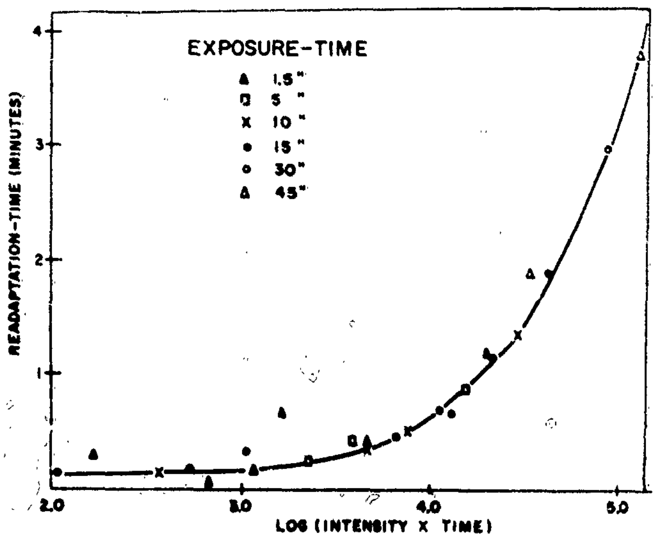

FIG. 6. RELATION BETWEEN READAPTATION-TIME AND LIGHT EXPOSURE AS MEASURED BY THE PRODUCT OF I × T

markable range of values. Constant products of I × T yield the same recovery-times for luminances varying at least 3 log units and for times of 1–30 sec. or more. While similar results have been shown for wide ranges of values for peripheral dark-adaptation,[9] the effect has not been reported previously for foveal dark-adaptation. Crawford states that complete

[9] Suchman and Weld. *op. cit.*, this JOURNAL, 51, 1938, 717-726; Mote and Riopelle, *op. cit.*, *J. comp. physiol, Psychol.*, 46, 1953, 49-55; Fry and Alpern, *op. cit.*, WADC Tech. Rep. 52-10, Part I, Nov. 1951; Crawford, *op. cit.*, *Proc. Roy. Soc.*, Series B, 133, 1946, 63-75; Haig, *op. cit.*, *J. gen. Physiol.*, 24, 1941, 735-751.

reciprocity holds for foveal vision only for durations of less than 1 sec., although failures in his data, in terms of total recovery-time, are obvious only at 30 sec. or longer.[10] Mote and Riopelle reported many instances of complete reciprocity for foveal dark-adaptation but also found a number of instances of failure.[11]

These studies differ from the present one in that they deal with foveal light-sensitivity rather than acuity. It is more important, perhaps, to note that there is a logical temporal limit beyond which the function cannot apply; that is, the exposure-time beyond which no further increase in recovery time is found.

Although this temporal limit will undoubtedly vary with the exposure-conditions, in the present experiment it was somewhat less than 1 min.; that is, recovery-times following 1-min. exposures were essentially the same as those following 45 sec. If a similar limit is assumed for the data of Mote and Riopelle, an assumption which is not at variance with their data,[12] the times required to reach a steady state, reported by them, give a curvilinear function against log I $\times$ T very similar to the one reported here.

The failure of reciprocity, where it occurs, is most interesting from a theoretical point of view. The only indication of failure in these data is at exposures of 45 sec., where recovery-times appear to be somewhat too long for simple reciprocity. This is in agreement with Crawford's data. He postulates a secondary photochemical process to account for the higher thresholds found with the longer exposures.[13]

From a practical point of view, however, the positive results are much more important. When a person is required to discriminate detail in a darkened environment, as in night driving, flying, or piloting a ship, his ability, after exposure to light, may be drastically reduced or may not be hindered at all. The amount of decrement depends upon the intensity and the duration of the exposure, and can be adequately predicted from the product of I $\times$ T.

Summary. The study was designed to measure the effect of various durations and intensities of light on the acuity-threshold of the dark-adapted fovea, by determining the time necessary to readapt following these exposures. The adapting lights were always presented foveally and

[10] Crawford, *op. cit.*, 69.
[11] Mote and Riopelle, *op. cit.*, *J. gen. Physiol.*, 34, 1951, 657-674.
[12] Mote and Riopelle, *op. cit.*, 1951, 665.
[13] Crawford, *op. cit.*, 75.

varied in brightness from 0.36 to 3,000 ft.-L., and in duration from 1 to 45 sec.

The resulting families of dark-adaptation curves show that the times necessary to readapt to the previously determined acuity-threshold vary systematically with the intensity and duration of exposure, from essentially zero for dim, brief lights to a maximum of about 5 min. for the longer, brighter ones. A most interesting aspect of the data is that the product of intensity and time gives a constant effect. When readaptation-time is plotted against I × T, a single curve results, which quite adequately fits the data-points.

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1. ORIGINATING ACTIVITY (Corporate author) U.S.Naval Submarine Medical Center, Submarine Medical Research Laboratory	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED
	2b. GROUP

3. REPORT TITLE

RECOVERY OF FOVEAL ACUITY FOLLOWING EXPOSURE TO VARIOUS INTENSITIES AND DURATIONS OF LIGHT

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Interim

5. AUTHOR(S) (Last name, first name, initial)

Kinney, JoAnn S. and Connors, Mary M.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
16 December 1966	9	13

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S) 464
b. PROJECT NO. MF022.03.03-9011.02	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

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13. ABSTRACT

The discrimination of visual detail at night or under conditions of dim illumination is required for the execution of many naval duties, such as piloting a ship, operating a periscope, or plotting navigation data. These tasks may depend more on good dark-adapted central visual acuity, which requires about five minutes of dark-adaptation, than on the more time-consuming peripheral night vision. It was the purpose of this study to determine the decrement in this ability caused by ordinary brief exposure to bright lights. Results showed that the recovery times varied systematically with the intensity and duration of the flash from essentially zero (or no effect) for the dim, brief flashes, to a maximum of five minutes (or complete loss of dark-adapted foveal acuity) for the brighter, longer flashes. Furthermore, the amount of the recovery time needed can be predicted by a knowledge of the product of the intensity X the duration of the flash. Thus the decrement produced by 30 seconds of 100 ft-L is the same as that caused by a 3-second flash of 1000 ft-L. The results are applicable to any operator needing good visual discrimination at night, since they assess the effect of any glare source, from the flare of a match to a burst of fire, on his ability to see his task.

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KEY WORDS	LINK A		LINK B		LINK C	
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